LABORATORY TESTS TO CHARACTERIZE THE MASTIC OF BITUMINOUS MIXTURES

Hugo Silva *
Research Assistant, Department of Civil Engineering, University of Minho, Guimarães, Portugal
* University of Minho, Department of Civil Engineering, Campus de Azurém, 4800-058 Guimarães, Portugal
hugo@civil.uminho.pt

Jorge Pais
Assistant Professor, Department of Civil Engineering, University of Minho, Guimarães, Portugal

Paulo Pereira
Full Professor, Department of Civil Engineering, University of Minho, Guimarães, Portugal

Silvino Capitão
Assistant Professor, Department of Civil Engineering, Superior Institute of Coimbra, Portugal

ABSTRACT: The bituminous mixtures are composed by more than one material (i.e. coarse and fine aggregates, filler and bitumen). The components are simultaneously present and contribute to the response of the mixture. Some studies have pointed out the mastic influence in the bituminous mixtures behaviour. The mastic is a mix of bitumen, filler and fine aggregates (maximum dimension of 2 mm) and represents the binder of the coarse aggregates in the bituminous mixtures. This research intends to observe the mechanical behaviour of the mastic as part of the bituminous mixture and it correlation with the bituminous mixtures. The mechanical performance of the mastic was observed in laboratory using tensile, compression and shear tests. Bituminous mixtures with the mastics defined in this work were made and then characterized using the same tests and the results were correlated to the mastic behaviour. The main conclusions explain the influence of the mastic in the performance of a bituminous mixture.

KEY WORDS: Bituminous mixtures, mastic, behaviour, tests, shear, tensile, compression

1. INTRODUCTION

The bituminous mixtures are composed by more than one material (i.e. coarse and fine aggregates, filler and bitumen) – they are not continuous and homogeneous; moreover, each of the components can be treated as a reference. The components are simultaneously present in the bituminous mixture and contribute to the response of the mixture [1]. As each component of the bituminous mixture can be treated as a reference and having in mind the influence of the mastic in the bituminous mixtures behaviour, this research intend to evaluate the mechanical behaviour of the mastic and correlate it with the bituminous mixture behaviour.

The mastic composition used in this research was based in a previous study developed by Silva [2], who studied the composition of the mastic within a wearing course bituminous mixture specified in the Portuguese standards [3]. In order to define the mastic composition, the mixtures were divided in 3 fractions (through sieving). Each one was used to verify it binder content and grading curve. The mastic definition used in this work corresponds of the mastic composition of a fraction of the bituminous mixture (binder and the fine material passed in sieve #10).

Slabs with eight different types of mastic were prepared in laboratory, and sawed in small specimens, which were tested to determine the shear, tensile and compression behaviour of the mastics. The mastics tested in this stage were prepared based on the composition indicated by Silva [2], with some variations, in order to evaluate the influence of composition parameters in the performance of the mastic. One of the mastics was submitted to an aging conditioning. The monotonic tests were based in a study done by Airey et al. [4], where tests were performed at 3 different speeds (8, 80 and 800 µm/s), at two different temperatures (15 and 25 ºC), and using an initial conditioning to simulate the influence of the water presence in the bituminous mixtures.

After this study, eight bituminous mixtures were produced using different gradation curves based on the studied mastics (all mixtures having the same grading curve over 2 mm). The mechanical performance of the mixtures was observed using the same test configurations used earlier on the mastics.

Finally, the mechanical performance of the bituminous mixtures was compared to the mastic behaviour, by correlating the results obtained in the previous tests on the mastic and on the bituminous mixtures. The main conclusions of this work were drawn from those correlations, allowing to understand the influence of the mastic in the bituminous mixtures.

2. MASTIC CHARACTERIZATION AND IT INFLUENCE IN THE MIXTURES BEHAVIOUR

The analysis of the existing literature concerning the mastic in conventional mixtures revealed that the main mastic characteristics can be addressed to the filler to bitumen adhesion and the rheological properties of the bitumen. The optimization of these characteristics has been shown to improve the bituminous mixture performance [5].

Dukatz and Anderson [6] referred that bituminous mixtures are composed by mineral aggregates bonded by a bituminous binder, the mastic. The mineral aggregates are distributed all over the mixture in sizes which range from coarse to fine. Properly compacted bituminous mixtures produce a structure whose stability, stiffness, and gearing properties are dependent on the interlocking of the aggregate and the mastic cohesiveness. The portion of the filler with particles thicker than the bitumen film contributes to the interlocking of the aggregate. The other portion of the filler with particles smaller than the thickness of the bitumen film is suspended in the bitumen and constitutes the binder in the mixture (the mastic).

The same authors studied the characteristics of the filler, which were correlated to the performance of the mastic and bituminous mixtures. The main conclusions of that research, for the materials tested, were:

1. Different mineral fillers produce different stiffening effects when they are added to bitumen. These effects are justified by the gradation of the filler as well as by the physico-chemical interactions between the filler and the bitumen;
2. Marshall stability and air voids are not affected by the type of mineral filler added to the mixtures;
3. Resilient modulus (short-term elastic response) do not reflect the stiffening effect of mineral filler;
4. Creep compliance (long-term non-recoverable response) is greatly affected by the filler stiffening effect;
5. The amount and type of mineral filler may cause compaction problems by stiffening of mixtures;
6. The field problem was due, most likely, to the excessive fines in the mixtures and not as a result of the bitumen;
7. Bitumen properties are not sufficient to describe the creep and compaction behaviour of bituminous mixtures made with fillers which manifest stiffening effects.

Some authors refer to the specific structure of the mastic mixtures. For small amounts of filler (application in hot mixes), the differences in the rheological properties are not very important. On the other hand, when the filler content reach high values, the rheological behaviour changes dramatically and this should be taken into account in the performance prediction [7].

The next stage in the study of the constituents interaction consists in paying attention specifically to the binder/aggregate interaction. This should be undertaken to accomplish a better understanding of the materials performance and a more effective prediction for road applications.

In the Belgian analytical mix design method [5], a bituminous mix is considered composed by a group of mineral coarse aggregates filled with mastic. Initially, the maximum volume available for mastic is determined and it is the same as the voids in mineral aggregates plus the volume of filler which is present in the aggregate.

Since the filler part of the mineral aggregates will be used to produce the mastic, the volume available for mastic includes the filler volume. This volume should be placed within pre-determined limits proposed by the Belgian standards. These limits are a function of the road type (i.e. highway, other roads, etc.) and layer type (i.e. wearing layer, base layer, etc.) and should be between 15.5 and 28.5%.

The next step is the determination of the mastic composition. The mastic composition must have thermal consistency and susceptibility to provide mixes with cohesion and stability adequate to the material used in the pavement as well as to the expected road traffic conditions. Its properties are influenced by the bitumen mechanical characteristics, the filler stiffness and by the ratio of filler to bitumen [8]. The Belgian method demonstrates the importance of the mastic characterization and the knowledge of its proportion in a bituminous mixture for mix design. By playing that role in the mix design, the mastic composition must be obviously known to improve its performance in order to achieve not only a better adhesion between the mastic and the coarse aggregates but also an overall improved bituminous mixture behaviour.

Concerning the study by Cupo-Pagano et al. [9], the Rigden voids are very important for the mastic characterization and for the mastic stiffening potential. The production of the mastic consists in a variation in the binder physical properties (an increase in the consistency and viscosity and an increase in the mixture stiffness), which can be measured by an application of a strain under static or dynamic conditions. The influence of the mastic in the mechanical properties of bituminous mixtures indicates that the main factors to be taken into account should be the type and the content of the material, in order to avoid undesirable phenomena in road pavements.

Although some other authors could be referred, it will be presented here the conclusions of Pilat et al. [10], concerning the influences of the mastic in the bituminous mixtures performance. These authors noted that, in the bituminous mixes, the binder is a set of bitumen-filler (i.e. mastics). The properties of mastics are determined by the type and quantity of components, by the rheological properties of bitumen and by the shape and structure of filler grains.

The analysis of the work of Pilat et al. [10] concerning the influence of mastics on the properties of bituminous mixtures, and specially its resistance to rutting, indicates that:

- It is reasonable to define the optimum composition of mastics, by determining the filler/bitumen ratio; the analysis of filler stiffening, rheological and standard properties;
- The addition of hydrated lime as part of the filler enhances the binder adhesion to the aggregate, improves the mastic cohesion and strengthens the bituminous mixture resistance to high-temperature deformations – ruts;
- The assessment of bituminous mixtures resistance to rutting can be conducted on the basis of tests on creep under static or dynamic pressure.

3. MECHANICAL STUDY OF THE MASTIC

3.1 Characterization of the Studied Mastics

In this part of the study, eight slabs with different types of mastic were prepared in laboratory, and small specimens were sawed, which were tested to determine the shear, tensile and compression behaviour of the mastics.

The mastics were prepared with different gradation curves, 2 types of bitumen (35/50 and 50/70), 2 types of filler (commercial limestone filler and recovered granite filler) and 3 binder contents. One mastic was submitted to previous conditioning to simulate the short term aging using the method recommended by Von Quintus et al. [11], and it involved the heating of the loose bituminous mixture, during a 24 hours, in a ventilated oven at a temperature of 135 ºC. The 8 mastics used in this part of the research are presented in Table 1.

3.2 Laboratorial Procedures

The specimens used in the tests were prepared in laboratory. The compaction was made by using one of the methods recommended during the SHRP program [12] which consists in compacting slabs in laboratory, through the repeated passage of a light cylinder with vibration over the bituminous mixture. Then, small specimens of $5\times5\times8$ cm^3 were sawed from the slabs. In the specimens tested to tensile, a small notch was made at middle height of the specimen, to control the occurrence of the failure in the mastic and the surface of rupture. The specimens were measured and the apparent density was determined.

Table 1. Mastics studied in this work and their properties

Type of mixture	**Mastic 1**	**Mastic 2**	**Mastic 3**	**Mastic 4**	**Mastic 5**	**Mastic 6**	**Mastic 7**	**Mastic 8**
Grading curve								
Passed #10	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Passed #20	73.8 %	73.8 %	73.8 %	73.8 %	73.8 %	83.0 %	52.3 %	73.8 %
Passed #40	52.1 %	52.1 %	52.1 %	52.1 %	52.1 %	68.8 %	26.0 %	52.1 %
Passed #80	28.9 %	28.9 %	28.9 %	28.9 %	28.9 %	40.9 %	15.1 %	28.9 %
Passed #200	16.2 %	16.2 %	16.2 %	16.2 %	16.2 %	23.3 %	9.2 %	16.2 %
Binder content	Medium 15.9 %	Inferior 13.6 %	Superior 18.2 %	Medium 15.9 %	Medium 15.9 %	Medium 19.9 %	Medium 9.8 %	Medium 15.9 %
Bitumen type	35/50	35/50	35/50	50/70	35/50	35/50	35/50	35/50
Filler type	Limestone	Limestone	Limestone	Limestone	Granite	Limestone	Limestone	Limestone
Initial aging	No	No	No	No	No	No	No	Yes
Study objective	Base composition	Binder Content superior	Binder Content inferior	Type of bitumen	Type of filler	Fine mastic	Coarse mastic	Aging

The monotonic tests were performed at 3 different test speed imposing 8, 80 and 800 µm/s displacement speed and two temperatures (15 and 25 ºC). Tests were also done on specimens, which were submitted to a previous conditioning, by simulating the mastic sensibility to the presence of water. The conditioning consisted in putting the specimens 1 hour in water with partial vacuum, followed by a period of 3 days of immersion in water at a temperature of 15 ºC. This conditioning was developed based by the conditioning defined by Lottman [13] to obtain the "short term relationships". Five different configurations of tests were done with 3 repetitions of each test:

Configuration 1 – displacement speed = 800 µm/s; Temperature = 15 ºC; No water conditioning.
Configuration 1 – displacement speed = 80 µm/s; Temperature = 15 ºC; No water conditioning.
Configuration 1 – displacement speed = 8 µm/s; Temperature = 15 ºC; No water conditioning.
Configuration 1 – displacement speed = 80 µm/s; Temperature = 25 ºC; No water conditioning.
Configuration 1 – displacement speed = 80 µm/s; Temperature = 15 ºC; Water conditioning.

The shear tests were done at constant height and the specimens were just leaned against the base plates. In Figure 1, it can be observed the type of specimens used in this test. The shear behaviour of the mastic can be observed in Figure 2.

In the tensile test the specimens were glued to the base plates for load application. Specimens tested in tensile can be observed in Figure 3 and the results are presented in Figure 4.

In the compression tests, the specimens were leaned against the base plates, and a pre-compression of 150 N was given to adjust the specimen to the test platens. Figure 5 presents the type of specimens used in this test. The compression behaviour of the mastic can be observed in Figure 6.

4. MECHANICAL BEHAVIOUR OF BITUMINOUS MIXTURES WITH DIFFERENT MASTICS

4.1 Characterization of Bituminous Mixtures Prepared with Different Mastics

To validate the laboratory tests used to characterize the mastic behaviour, bituminous mixtures were produced with the mastics used in the previous analysis and tested in the same tests and configurations. The bituminous mixtures produced with the previous mastic were design using the procedure presented in Figure 7.

Figure 1. Type of mastic specimens used in the shear test (before and after test)

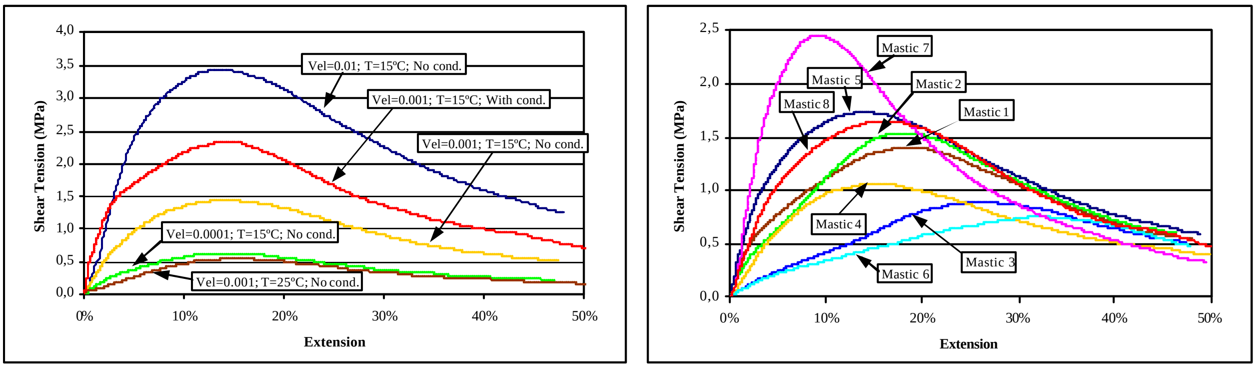

Figure 2. Shear tension of the mastic as function on the applied extension

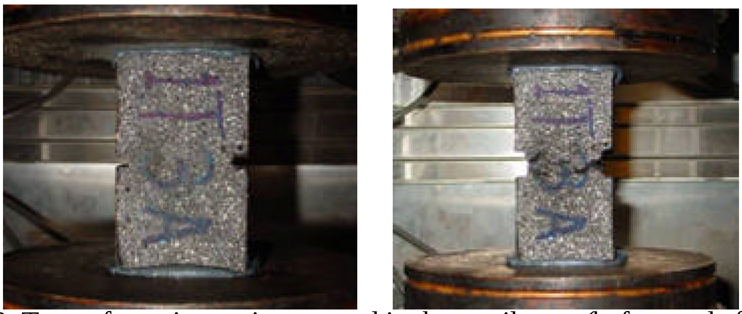

Figure 3. Type of mastic specimens used in the tensile test (before and after test)

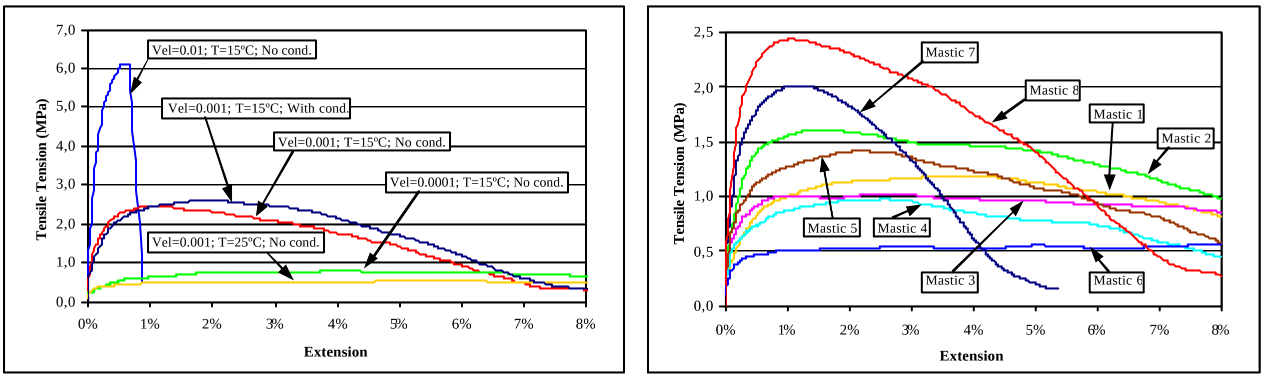

Figure 4. Tensile tension of the mastic as function on the applied extension

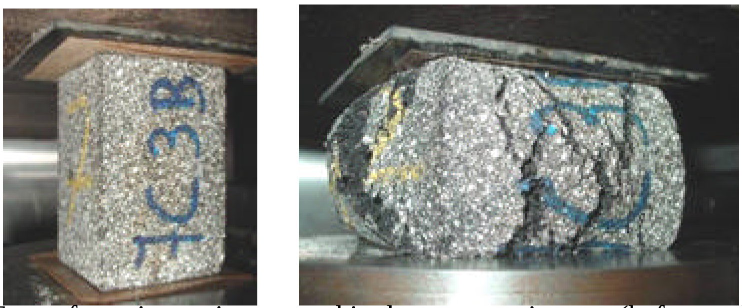

Figure 5. Type of mastic specimens used in the compression test (before and after test)

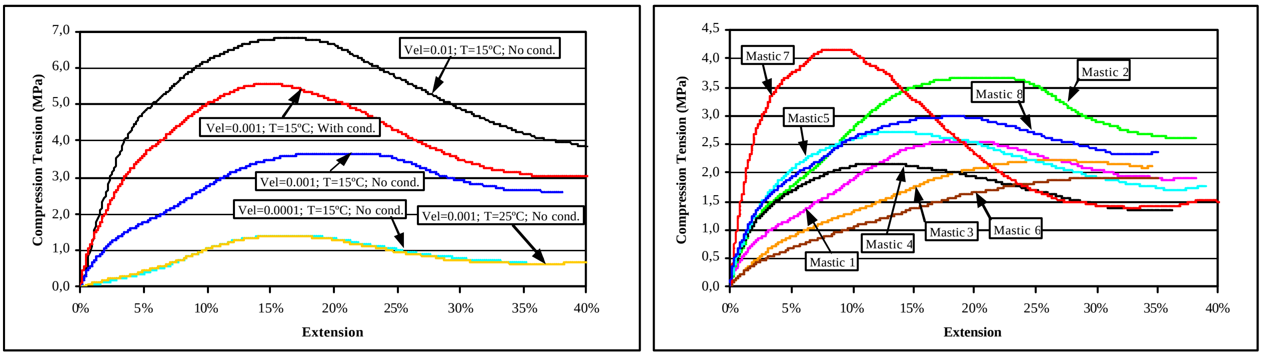

Figure 6. Compression tension of the mastic as function on the applied extension

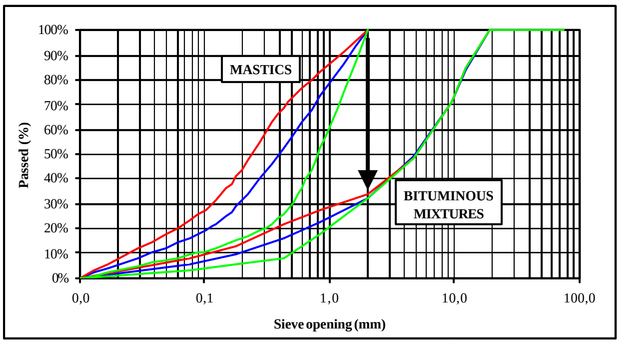

Figure 7. Method to obtain the bituminous mixtures from the mastics composition

In Table 2, the eight bituminous mixtures obtained from the mastic compositions and from the Portuguese APORBET standards [3] for the wearing course bituminous mixtures are presented.

4.2 Laboratorial Procedures

Eight bituminous mixtures were prepared and tested exactly as in the previous chapter. So, the only differences to be presented here, in comparison to the last chapter, are the type of specimens and the results obtained in the different tests.

The type of specimens used in this test is presented in Figure 8. The shear behaviour of the mastic can be observed in Figure 9.

The specimens tested in tensile can be observed in Figure 10 and the results are presented in Figure 11.

Figure 12 presents the type of specimens used in this test. The compression behaviour of the mastic can be observed in Figure 13.

Table 2. Bituminous mixtures studied

Type of mixture	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Grading curve								
Passed #3/4”	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Passed #1/2”	83.7 %	83.7 %	83.7 %	83.7 %	83.7 %	83.7 %	83.7 %	83.7 %
Passed #3/8”	71.2 %	71.2 %	71.2 %	71.2 %	71.2 %	71.2 %	71.2 %	71.2 %
Passed #4	47.8 %	47.8 %	47.8 %	47.8 %	47.8 %	47.8 %	47.8 %	47.8 %
Passed #10	32.5 %	32.5 %	32.5 %	32.5 %	32.5 %	32.5 %	32.5 %	32.5 %
Passed #20	24.0 %	24.0 %	24.0 %	24.0 %	24.0 %	27.0 %	17.0 %	24.0 %
Passed #40	16.9 %	16.9 %	16.9 %	16.9 %	16.9 %	22.4 %	8.5 %	16.9 %
Passed #80	9.4 %	9.4 %	9.4 %	9.4 %	9.4 %	13.3 %	4.9 %	9.4 %
Passed #200	5.3 %	5.3 %	5.3 %	5.3 %	5.3 %	7.6 %	3.0 %	5.3 %
Binder content	Medium 5.2 %	Inferior 4.4 %	Superior 5.9 %	Medium 5.2 %	Medium 5.2 %	Medium 6.5 %	Medium 3.2 %	Medium 5.2 %
Bitumen type	35/50	35/50	35/50	50/70	35/50	35/50	35/50	35/50
Filler type	Limestone	Limestone	Limestone	Limestone	Granite	Limestone	Limestone	Limestone
Initial aging	No	No	No	No	No	No	No	Yes
Study objective	Base composition	Binder Content superior	Binder Content inferior	Type of bitumen	Type of filler	Fine mastic	Coarse mastic	Aging

Figure 8. Type of bituminous mixture specimens used in the shear test (before and after test)

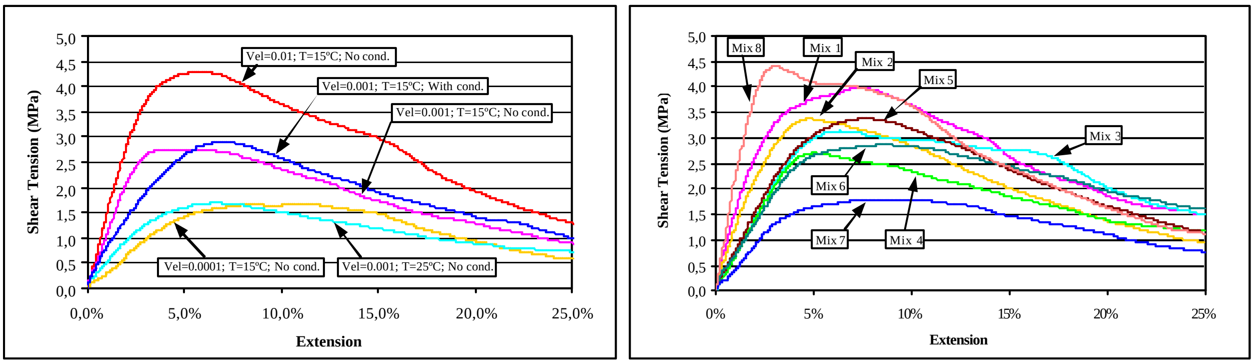

Figure 9. Shear tension of the bituminous mixture as function on the applied extension

5. COMPARISON BETWEEN BITUMINOUS MIXTURES AND MASTIC

In order to evaluate the influence of the mastic on the bituminous mixtures behaviour, in this section, the properties obtained for the mastics were related to the characteristics of the bituminous mixtures. Thus, the comparison between the results of the mastics and of the bituminous mixtures, obtained in the compression, shear and tensile tests, is presented in Figures 14, 15 and 16.

It is observed that there is a good correlation between the behaviour of the bituminous mixtures and the behaviour of the original mastic. However, certain factors, such as the voids volume, introduce a variability degree which avoid a perfect correlation.

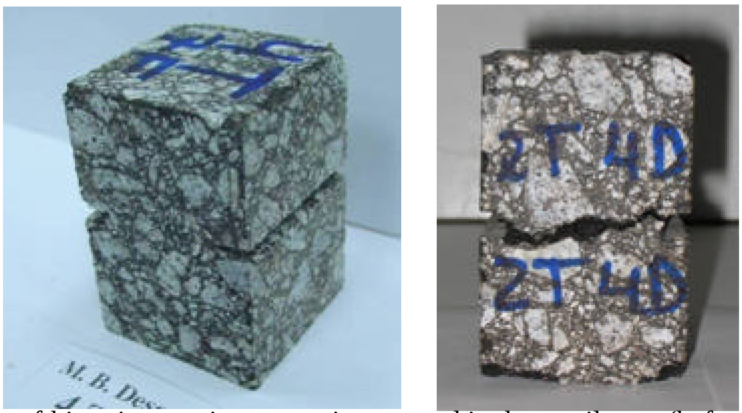

Figure 10. Type of bituminous mixture specimens used in the tensile test (before and after test)

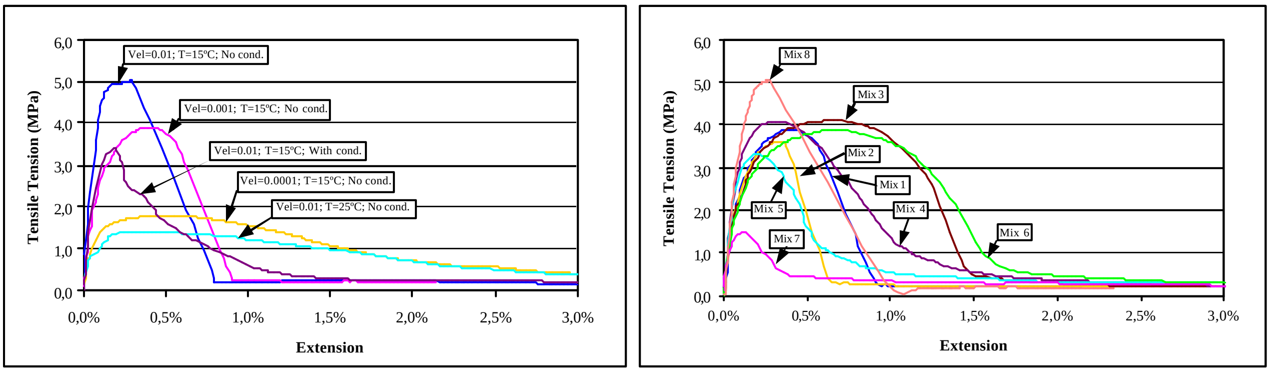

Figure 11. Tensile tension of the bituminous mixture as function on the applied extension

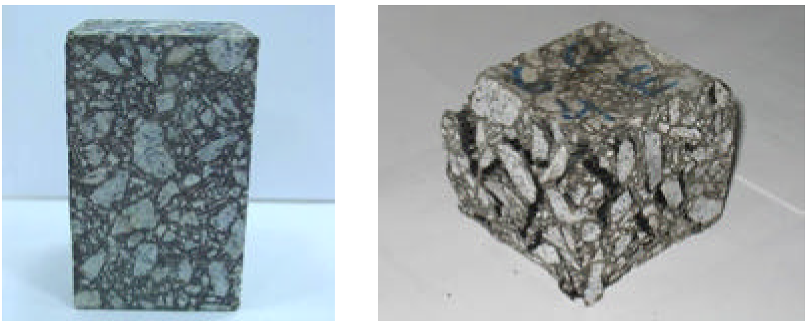

Figure 12. Type of bituminous mixture specimens used in the compression test (before and after test)

6. CONCLUSIONS

The results from the study of the mastic allow to conclude that the increase of the mastic binder content (mastics 6 and 3) reduces the mastic performance. The same conclusion can be applied to the mastic with granite filler. The aging procedure increased the resistance of the mastic.

The main conclusion from the mechanical behaviour of the bituminous mixtures is that the increase of the binder content (mix 6 and 3) reduces the bituminous mixture performance. The same conclusion can be applied to the mastic with 50/70 penetration bitumen. The aging procedure increased greatly the resistance of the bituminous mixture.

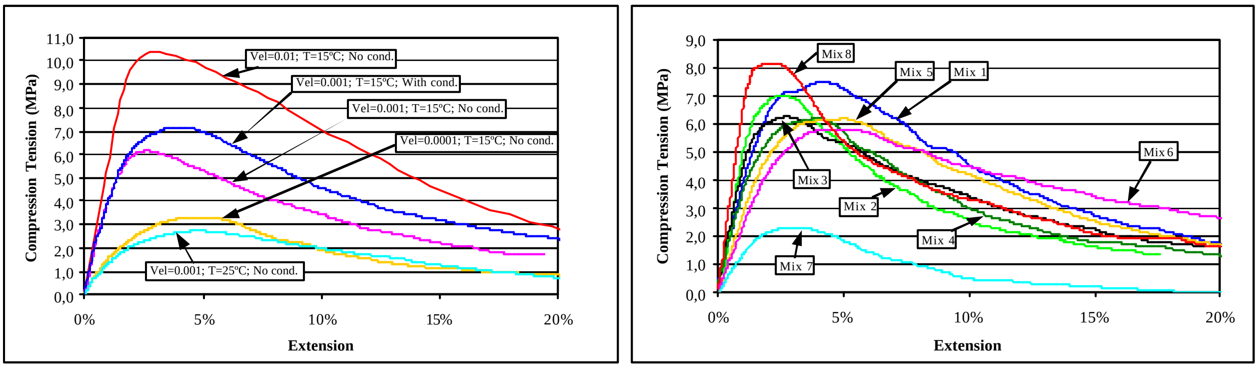

Figure 13. Compression tension of the bituminous mixture as function on the applied extension

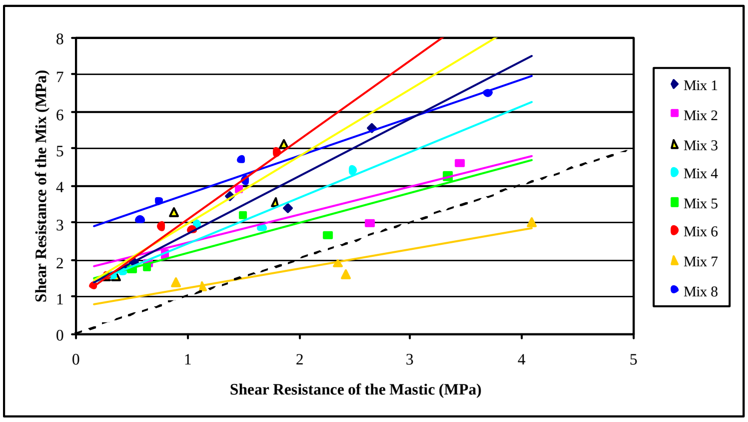

Figure 14. Comparison between the mastic and the bituminous mixture shear resistance

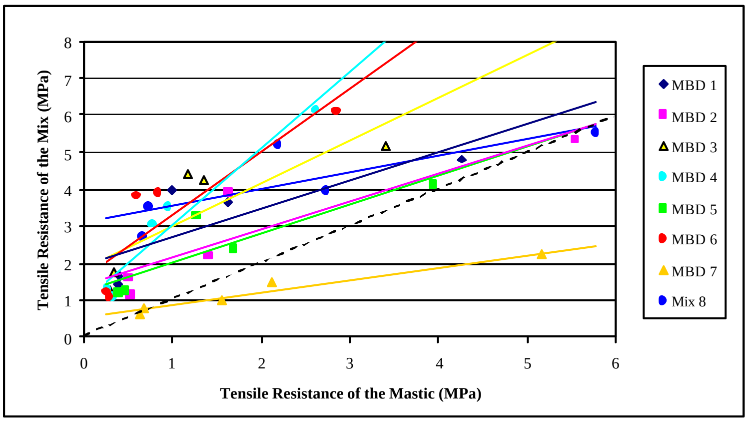

Figure 15. Comparison between the mastic and the bituminous mixture tensile resistance

The analysis of the relationship between the properties of the mastic and the bituminous mixtures allowed to conclude that there is a good correlation between both. In the three types of tests it was possible to observe that the mixtures with higher binder contents (Mix 3 and 6) and with a softer bitumen (Mix 4) were the ones which had a significant resistance, concerning the resistance of its mastic. On the other hand, the bituminous mixtures with reduced binder contents (Mix 2 and 7) and with granite filler (Mix 5) were the ones which presented a smaller resistance in comparison to its mastic.

From this study, it can be concluded that the mechanical behaviour of the mastics presents the same trend as the mechanical behaviour of the bituminous mixtures in both test performed and for all test configurations.

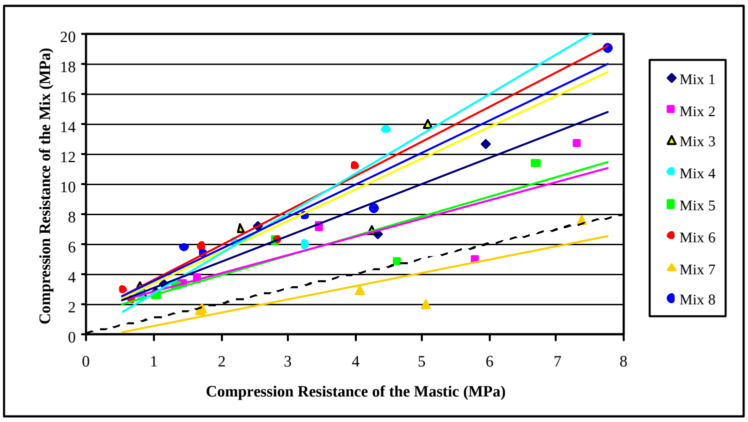

Figure 16. Comparison between the mastic and the bituminous mixture compression resistance

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